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ON THE FASOLDT STAGE MICROMETER.

By PROF. T. C. MENDENHALL, Ph. D., Columbus, O.

[PLATES V. AND VI.]

At the meeting of the American Society of Microscopists, in Columbus, in 1881, a stage micrometer was presented to the Society by its maker, Mr. Fasoldt, of Albany, N. Y. It was formally accepted, and at the close of the meeting the Society's Custodian, Dr. Fell, turned it over to the writer, with the request that a critical examination of it should be made, and the results reported to the Society at its next meeting. The pressure of other professional duties, necessary and unavoidable, has made it impossible to give the micrometer as thorough and complete an investigation as could have been desired. Nevertheless, a considerable number of measurements have been made, amounting in all to five or six hundred, and it is believed that the results given below are entitled to a sufficient degree of credit as to accuracy as to render them of considerable value in establishing the merits of the ruling. They are now submitted to the Society, with the thanks of the writer for having been permitted to perform a task which, while it involved much labor, has proved to be a real pleasure.

Among the instrumental appliances made use of in the investigation, there is to be mentioned, first, a massive and well-built stand by Ross, with rotating and mechanical stage, for the use of which I am indebted to the kindness of Dr. C. Leo Mees. The solidity and firmness of this stand, combined with the ease and delicacy of the movement of its various parts, render it an admirable instrument for all purposes of micrometric research.

What is commonly called a spider-line or cob-web micrometer eye-piece, belonging to the Physical Department of the Ohio State University, was easily adapted to the stand. This eye-piece was made by John Browning, of London; the screw has a pitch of one one-hundredth of an inch, and the workmanship of the whole is most excellent.

In the various measurements four different objectives were used. They were a Crouch $\frac{2}{3}$ and a Ross $\frac{1}{10}$ immersion, belonging to Dr. Mees, and two homogeneous immersion objectives, a Gundlach $\frac{1}{8}$ and a Zeiss $\frac{1}{12}$, belonging to Prof. A. H. Tuttle. In addition to the use of these excellent objectives, I am indebted to Prof. Tuttle for many valuable suggestions concerning their manipulation, being fortunate in having his well-known skill and experience at my command during the progress of the work.

The micrometer plate contains, within its extreme lines, seventy-five spaces in all. These are distributed as follows:

Five spaces of $\frac{1}{100}$ inch.
Ten spaces of $\frac{1}{200}$ inch.
Ten spaces of $\frac{1}{1000}$ inch.
Twenty-five spaces of $\frac{1}{5000}$ inch.
Twenty-five spaces of $\frac{1}{10000}$ inch.

The most essential feature in a stage micrometer is regularity of ruling, rather than absolute width of space, as the latter can easily be determined to a sufficient degree of accuracy, once for all, by a comparison with a standard. In these measurements it was uniformity of width of space which was especially under consideration. Each space was measured five times, the means only being given below. In these numbers the unit is one division of the micrometer screw-head, which was never read closer than the nearest unit in the individual measurements.

The measurement began with the first one-hundredth-inch space. In the tables given below, the first column contains the number of the space, the second the width of the space, being the mean of five measurements, and, as an indication of the agreement of the individual measures among themselves, the third shows the greatest difference between any single measure and the mean of the set of five.

The object of the work being to discover differences, in every case except the twenty-five measurements on the one-hundredth-inch spaces, the fixed cross of the micrometer was set on one line, and the movable one adjusted to the other, thus reducing the necessary motion of the screw to a minimum.

TABLE OF RESULTS.

Width of space, $\frac{1}{100}$ inch. Objective, Crouch $\frac{2}{3}$.

Space.	Width.	Greatest dif. from mean.
1	2033.2	1.7
2	2035.4	1.6
3	2033.8	1.3
4	2031.7	1.7
5	2036.6	1.4

Mean of all, 2034.1. Greatest difference from mean, 2.5

Width of space, $\frac{1}{200}$ inch. Objective, Crouch $\frac{2}{3}$.

Space.	Width.	Greatest dif. from mean.
1	1019.4	1.4
2	1015.8	.8
3	1016.2	.8
4	1015.5	1.2
5	1014.4	1.1
6	1016.2	.8
7	1014.8	1.2
8	1018.2	.8
9	1019.	.5
10	1017.8	.8

Mean of all, 1016.6. Greatest difference from mean, 2.8.

Width of space, $\frac{1}{1000}$ inch. Objective, Gundlach $\frac{1}{8}$.

Space.	Width.	Greatest dif. from mean.
1	1005.2	1.8
2	996.6	.4
3	1010.8	1.2
4	999.8	.8
5	1006 2	.8
6	996.4	1.4
7	1016.4	1.6
8	992.6	1.6
9	999.8	1.2
10	1002.	1.

Mean of all, 1002.6. Greatest difference from mean, 13.8.

Width of space, $\frac{1}{5000}$ inch. Objective, Zeiss $\frac{1}{12}$.

Space.	Width.	Greatest dif. from mean.
1	331.4	1.6
2	326.2	1.8
3	326.2	1.2
4	319,6	1.6
5	320.8	1.8
6	328.8	1.2
7	334.2	1.2
8	325.4	1.4
9	324.	1.
10	328.	0.
11	332.	1.
12	331.2	1.2
13	325.4	.6
14	324.2	1.8
15	328.2	.8
16	330.2	1.8
17	330.6	.6
18	324.4	1.6
19	323.6	.4
20	333.2	1.2
21	327.8	.8
22	327.6	1.4
23	321.4	1.6
24	336.0	1.
25	327.8	.8

Mean of all, 327.5. Greatest difference from mean, 8.5.

Width of space, $\frac{1}{10000}$ inch. Objective, Zeiss $\frac{1}{12}$.

Space.	Width.	Greatest difference from mean.
1	158.	2.
2	157.2	1.8
3	161.8	1,2
4	165.8	1.2
5	161.2	2.2
6	161.8	1.8
7	161.4	1.6
8	162.8	1.2
9	153.6	1.4
10	157.8	2.2
11	178.4	.6
12	174.6	1.4
13	160.4	2.6
14	156.2	1.8
15	166.4	1.4
16	159.8	2.2
17	163.8	1.2
18	155.2	1.2
19	159.2	.8
20	157.	2.
21	173.8	1.2
22	159.4	1.4
23	162.6	1.4
24	165.8	.8
25	165.2	1.8

Mean of all, 162.4. Greatest difference from mean, 16.

An examination of the above tables shows that in the one-hundredth-inch spaces, the greatest deviation from the mean width is a little more than one-tenth of one per cent. of the whole; also that, while the apparent deviation as shown by a percentage of the whole increases as the spaces diminish in width, this increase is nearly inversely proportional to the width of the spaces. Thus, in the ten-thousand-to-the-inch spaces, the greatest deviation from the mean is about ten per cent., and this is as it should be if the same absolute error had been committed throughout. As the total space covered by these lines is only one-fourth as great as that by one of the first spaces, it would seem to indicate that the error was one incident to the act of drawing the line, and not to imperfections in the screw. It will be seen, however, that the deviation in the case of five-thousand-to-the-inch spaces is less than it should be, according to this hypothesis, but this deficiency might be easily accounted for.

This regularity in the increase of the percentage of deviation might seem, at first, to be explainable upon the supposition that the errors were accidental errors of observation; but the table shows that the range of the individual measurements was always less than the range of the spaces, the latter being, in the last set, about ten times as great as the former.

The errors will be found to tend towards periodicity. This, as well as the extent and nature of the deviation, will be much better seen by an examination of the accompanying plate V., in which the variations from the mean are plotted for each group of spaces.

In the first diagram the unit of the vertical scale is one-tenth of one per cent. The deviation increases so rapidly, as the spaces diminish, that it is necessary to reduce the vertical scale for the last two groups, and, for convenience in making comparisons, the third group, in which the space equals one one-thousandth of an inch, is shown in the reduced scale on plate VI. The unit of the vertical scale in this diagram is one per cent.

A considerable series of measurements upon other rulings was made for the purpose of seeing how they compared in uniformity of spacing with the Fasoldt plate. Micrometers by Ross and by Rogers were thus examined. Measurements were also made upon a diffraction grating by Rutherford, having nominally 4330 lines to the inch. The latter was measured in bundles of twenty-two spaces, each giving, approximately, one two-hundredth of an inch, with which space on the Rogers and Fasoldt plates it was compared. As the time at my command permitted only a single measurement of each space in these comparative determinations, a re-measurement was made of that set of lines on the Fasoldt plate under precisely the same conditions. The results are exhibited in the tables below.

ROSS STAGE MICROMETER.

Spaces $\frac{1}{1000}$ in.	Obj. Gundlach $\frac{1}{8}$
1	973
2	948
3	979
4	977
5	930
6	981
7	933
8	1010
9	1006
10	1045

Mean of all, 978.2. Greatest difference from mean, 48.2.

FASOLDT'S STAGE MICROMETER.

Spaces $\frac{1}{200}$ in.	Obj. Crouch $\frac{2}{3}$.
1	1020
2	1014
3	1014
4	1014
5	1013
6	1014
7	1013
8	1015
9	1017
10	1014

Mean of all, 1014.8. Greatest difference from mean, 5.2.

ROGER'S STAGE MICROMETER.

Spaces $\frac{1}{200}$ in.	Obj. Crouch $\frac{2}{3}$.
1	1021
2	1023
3	1024
4	1016
5	1021
6	1020
7	1031
8	1022
9	1025
10	1021

Mean of all, 1022.4. Greatest difference from mean, 8.6

DIFFRACTIVE GRATING BY RUTHERFORD.

Spaces, group of 22; 4320 to the inch.	Objective, Crouch $\frac{2}{3}$.
1	1031
2	1031
3	1033
4	1029
5	1034
6	1032
7	1032
8	1031
9	1031
10	1032

Mean of all, 1031.6. Greatest difference from mean, 2.6.

The Ross rulings, when compared with the same spaces on the Fasoldt, do not make a good showing. It will be seen that the greatest deviation from the mean in the Ross is about five per cent., while in the Fasoldt it is but little more than one per cent. It must be remembered, however, that only single measurements were taken of the Ross spaces; but even if allowance be made for this fact, it falls far behind the Fasoldt in uniformity. On comparing the results in the last three sets of measurements, it will be seen that the Rutherford grating ranks first, the Fasoldt plate second, and the Rogers plate third, the deviation from the mean in the last being two and three times that in the second and first.

The Rogers plate is one which was ruled several years ago, and I am glad to say that it does great injustice to the most excellent work which Mr. Rogers has more recently produced.

Soon after I had completed the measurements already given, the subject of micrometry happened to be referred to in a conversation with Gov. J. D. Cox, and he spoke in high terms of a micrometer which Mr. Rogers had ruled for him about a year before. Gov. Cox kindly forwarded this plate to me a few weeks ago, and I have examined it with much pleasure.

I have only found leisure to make a measurement of twenty spaces of the one-hundredth millimeter divisions, and of these only two measurements of each space were taken. In the results shown below, the means are given.

NEW ROGERS MICROMETER.

Width of space, $\frac{1}{100}$ millimeter. Objective, Ross $\frac{1}{10}$.

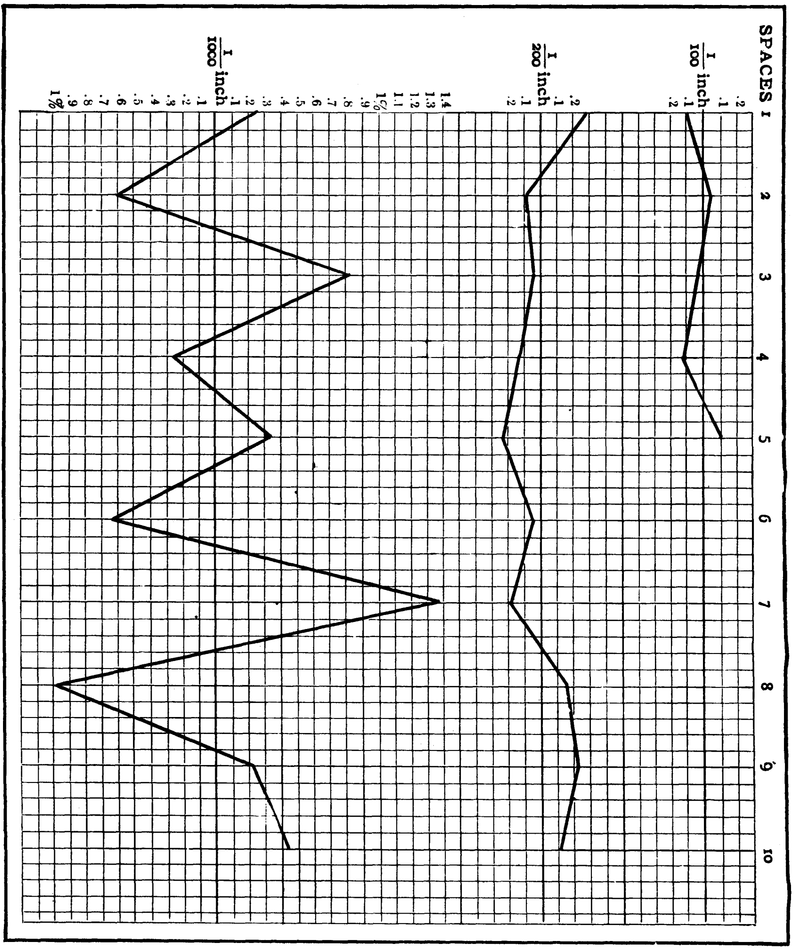
1	638.5	11	632
2	633.5	12	636.5
3	633	13	633
4	641.5	14	637.5
5	637.5	15	636.5
6	637.5	16	639
7	638.5	17	635,5
8	635	18	632.5
9	635	19	636.5
10	636	20	640.5

Mean of all, 636.2. Greatest difference from mean, 5.3.

As $\frac{1}{100}$ m. m. is approximately equal to $\frac{1}{2500}$ inch, there are no spaces in the previous sets with which these can be quite fairly compared. It will be seen, however, that the plate makes a better record for uniformity than any other micrometer examined. In width of space it lies between the Fasoldt $\frac{1}{1000}$ inch and $\frac{1}{5000}$ inch groups; the deviation from the mean in the first is somewhat more than one per cent., while in the new Rogers it is only about eight-tenths of one per cent., and this, too, with only two measurements of each space, against five for the Fasoldt. I think it may be safely said that both the Fasoldt and the Rogers micrometers are sufficiently uniform in their ruling to satisfy all of the ordinary demands of microscopic measurement. In fact, the spaces with which we are here dealing are exceedingly minute. A deviation of one per cent. from one one-hundredth of a millimetre, means a variation of $\frac{1}{10000}$ of a millimetre, or about $\frac{1}{250000}$ of an inch, and it almost requires the evidence of actual practice in measurement to convince one that such a deviation can be detected.

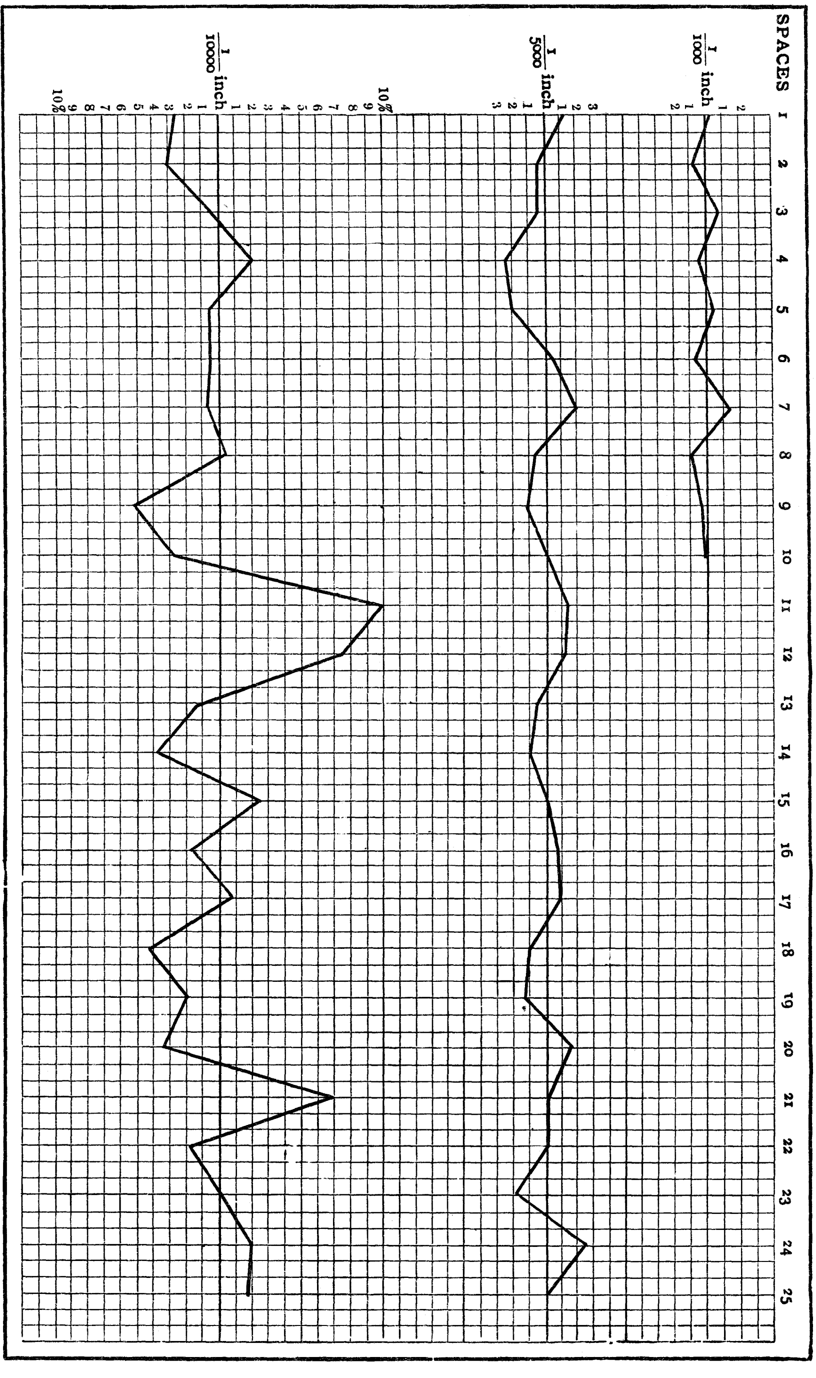
NOTE.—Since the above was written, I have received from Mr. Fasoldt two new micrometers ruled after a correction of the absolute value of the inch of his machine. I have not yet been able to examine them, but I shall do so at the earliest moment, and report the results to the Society, along with one of the plates, which Mr. Fasoldt desires shall be substituted for that already in the Society's possession. A series of measurements made by Mr. Chas. A. Schott, of the United States Coast Survey, a memorandum of which I have received, shows that a half inch of the previous ruling was longer than the Coast Survey Standard by 1-5000 of an inch. Mr. Fasoldt believes that his machine is now corrected so that it rules the Coast Survey Standard inch within the limits of observation and measurement. The new scales will doubtless equal the old in the great regularity of their ruling, and will be the better for being nearer the United States Standard inch.

PLATE V.



H. CHANDLER SC.

PLATE VI.



H. CHANDLER SC.